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REPORT DOCUMENTATION PAGE

Form Approved
OMB NO. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	August 14, 1997	Interim, June 1997 - August 1997

4. TITLE AND SUBTITLE

THz Radiation Source Trough Periodically Modulated Structures

h

5. FUNDING NUMBERS

C
N 68171-96-C-9015

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8. PERFORMING ORGANIZATION REPORT NUMBER

7th Interim Report

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U.S. Army Research Office
P.O. Box 12211
Research Triangle Park, NC 27709-2211

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

WK2Q6C-7372-EE01

11. SUPPLEMENTARY NOTES

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12a. DISTRIBUTION / AVAILABILITY STATEMENT	12 b. DISTRIBUTION CODE
Approved for public release; distribution unlimited.	

13. ABSTRACT (Maximum 200 words)

In the time period since the last report we have concentrated our activities in in measuring plasmon replicas in low doped bulk GaAs using the technique of hot electron spectroscopy. For this purpose a new four terminal device was fabricated abd tested . The IV curves are very promising and show some pronounced features which have to be analysed together with theoretical calculations.

In addtion we have concentrated our efforts on new specially designed structures together with the Boston group to achieve strong population inversion. Design and subsequent growth of a series of nanostructures with appropriate injector-extractor arrangements for two different doping levels was realised.

14. SUBJECT TERMS	15. NUMBER IF PAGES
Carrier injection, quantum wires, THz sources, superlattice spectroscopy	
	16. PRICE CODE

17. SECURITY CLASSIFICATION OR REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

THz RADIATION SOURCE THROUGH PERIODICALLY MODULATED STRUCTURES

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CONTRACT NO. N68171-96-C-9015

7 th Interim Report

June 1997- August 1997

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Four Terminal Device (FTD)-Detection of plasmon emission

In the previous report a three terminal device was described which was used to study the quenching of ballistic miniband transport in biased superlattice structures. In the last period we developed a four terminal device (FTD), including a resonant tunnelling diode as an injector in order to inject a very narrow electron energy distribution.

The four terminal device structure is decined to allow for the possibility to set up conditions for the beam-plasma instability. When injecting an electron density with a narrow energy distribution, a strong disturbance of the cold electron plasma should occur according to the prediction of Bakshi and Kempa.. The plasma instability leads to local oscillations of the charge density, and should produce efficient emission at the frequency of the growing plasma waves. This frequency is here in the THz range.

The concept of the ballistic electron four terminal device includes a resonant tunnelling diode grown in between the highly doped emitter and base contact. The base contact, which has to be very thin (10 nm) in order to minimise the lost due to electron-electron scattering in the base, is separated from the low doped ($n=1.10^{17}$ cm^{-3}) GaAs layer by a 90 nm AlGaAs barrier. The potential barrier height is chosen to be 15 meV. Between the 200 nm thick doped GaAs layer and the collector contact a second resonant tunnelling barrier is grown, serving as an analyser of the ballistic hot electron beam. When tuning the injector into the resonant condition of the tunnelling diode, we are able to produce a sharp electron beam. This device is used to observe directly the relaxation of hot carriers via plasmon emission, in a low doped ($n=1.10^{17}$ cm^{-3}) GaAs drift region which is contacted to the ground in order to avoid undesired charging of this drift region.

In Fig. 1 the calculated equilibrium conduction band energy diagram including band bending is shown. The hatched areas indicate the doped GaAs contact layers. Scanning electron microscopy (SEM) was used to verify the MBE grown layer structure. A commercial CV-

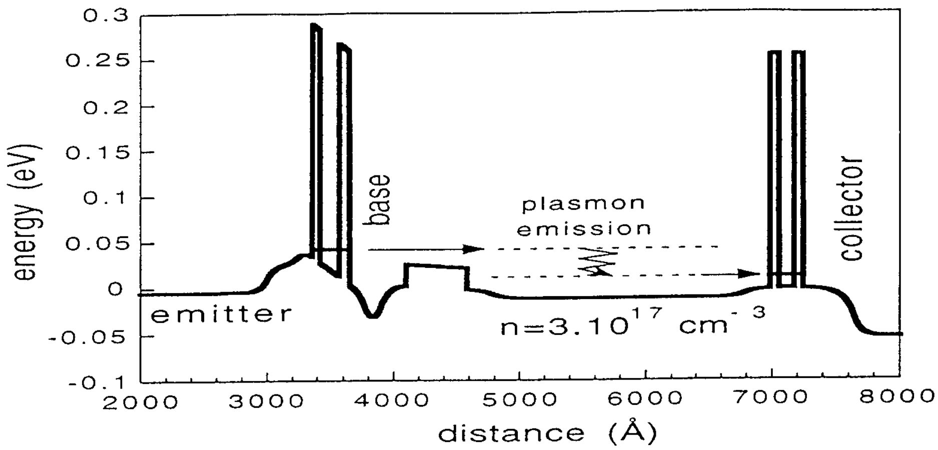


Figure 1: Conduction band diagram of a four terminal device. The hatched areas indicate the doped layers.

doping profiler was used to measure the carrier concentration within the structure which is shown in Fig. 2.

The fabrication of the four terminal device includes the following steps: selective wet etching of the emitter mesas (20x20 μm^2), two unselective $SiCl_4/Ar$ reactive ion etching (RIE) processes to the second base and to the collector. The etch depth is verified by measuring the CV-doping profile after every etch step. Standard AuGeNi alloy is used to form the ohmic contact to the doped GaAs layers, Si_3N_4 is applied in order to isolate the device from the extended bonding contacts.

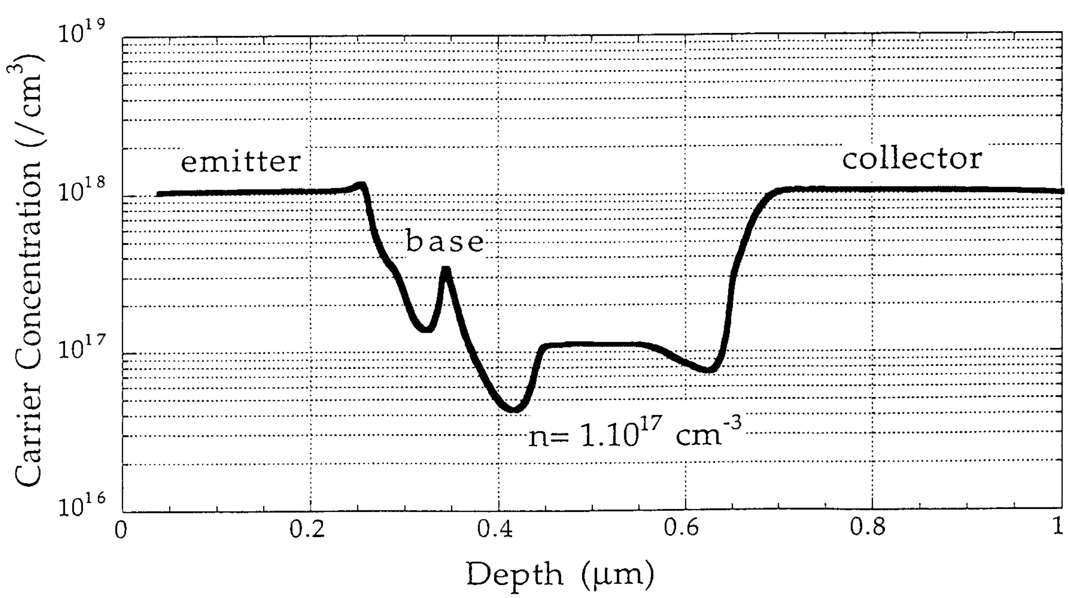


Figure 2: Carrier concentration vs depth of a four terminal ballistic hot electron device.

A SEM picture of the device is shown in Fig. 3. The two base contacts are evaporated at the side of the 20x20 μm^2 emitter mesa. The AuGeNi emitter contact is used as an etch mask for the first etch step.

The I-V characteristics of the injector and of the analyser resonant tunnelling diode (RTD) measured at 4.2 K is shown in Fig. 4 and Fig. 5 respectively. The I-V is highly asymmetric as expected since the structure has different spacers and drift regions on each side of the resonant tunnelling barrier. The emitter-base RTD shows a sharp resonance at 100 mV and at about 200 mV for negative voltages and at about 120 mV for positive bias. The analyser RTD shows a peak at about 100 mV.

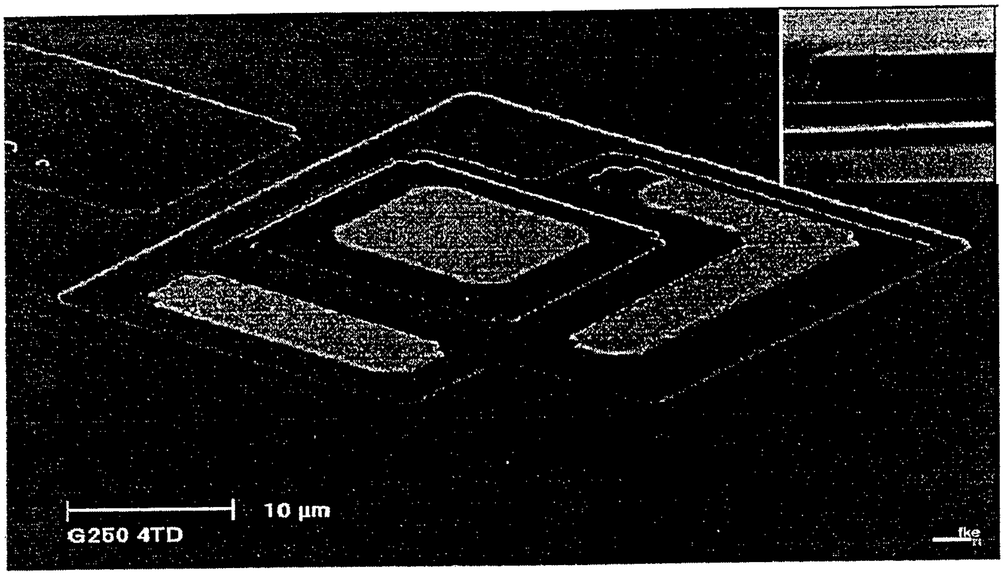
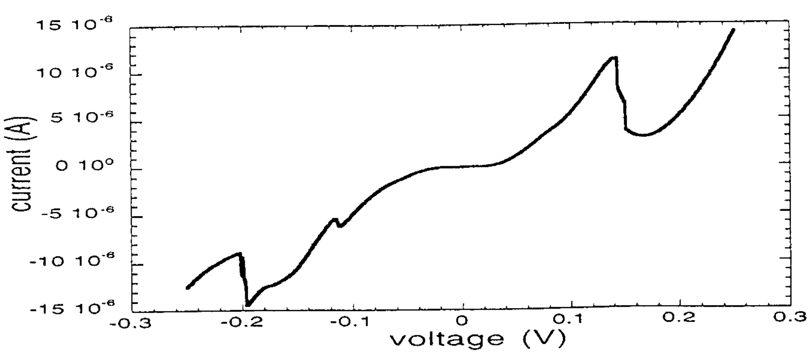


Figure 3: SEM picture of a four terminal device. The inset shows a side view of the device.

Since we observe a leakage current between the base and the low doped GaAs layer a second prototype is grown. The thickness of the AlGaAs barrier, separating base and the low doped GaAs layer is chosen to be 130 nm which prohibits tunnelling between these two contacts.

Figure 4: I-V of the injector resonant tunnelling diode



In addition the four terminal device design is used to resolve the single Stark states of a short period superlattice, since the injected electron distribution is much narrow than the spacing between the single states. The superlattice structure is grown between a second very thin base contact and the collector.

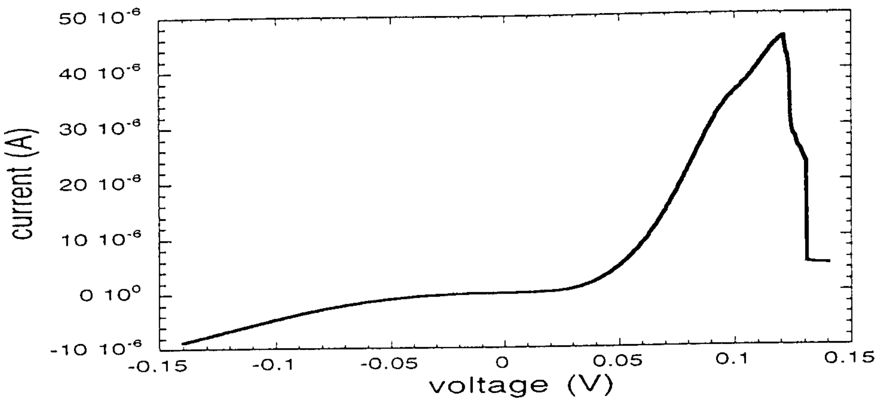


Figure 5: I-V of the analyser resonant tunnelling diode

Injector-extractor scheme as a THz emission source

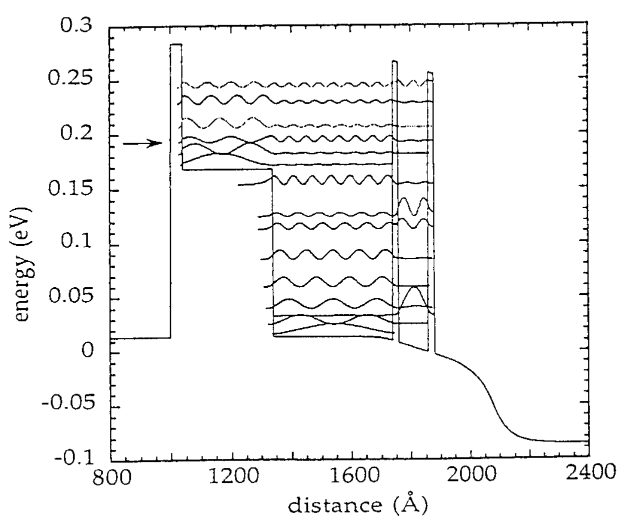


Figure 6: Conduction band structure of the coupled resonant quantum well. The squared electron wave functions are plotted at the corresponding energy levels.

The generic structure (shown in Fig. 6) consists of a two section quantum well, coupled to a resonant tunnelling filter. The two-section active region was designed to yield essentially a three miniband arrangement in which the upper miniband is strongly coupled to one of the electron reservoirs, outside the quantum well, and therefore subject to strong carrier injection. The lower miniband, located more than 36 meV below the upper miniband is also heavily populated by intersubband transitions from the upper miniband, mediated by LO phonon emission. In contrast, the middle miniband, located less than 20 meV below the

upper miniband, will not suffer such a massive flooding mediated by LO phonon emission. The level has a lower population which can be further decreased by coupling it to the other reservoir outside the quantum well.

Fig. 7 shows the derivative of the measured current versus applied voltage for two different samples: Sample g206 is doped in the quantum well, while sample g272 is undoped. The measured characteristics are consistent with the calculated miniband arrangement of the designed structure, demonstrating highly controlled sample growth. However the details of the current characteristics have to be compared with calculations to understand the steep increase of the current for the doped sample. To further increase the current through the structure and to

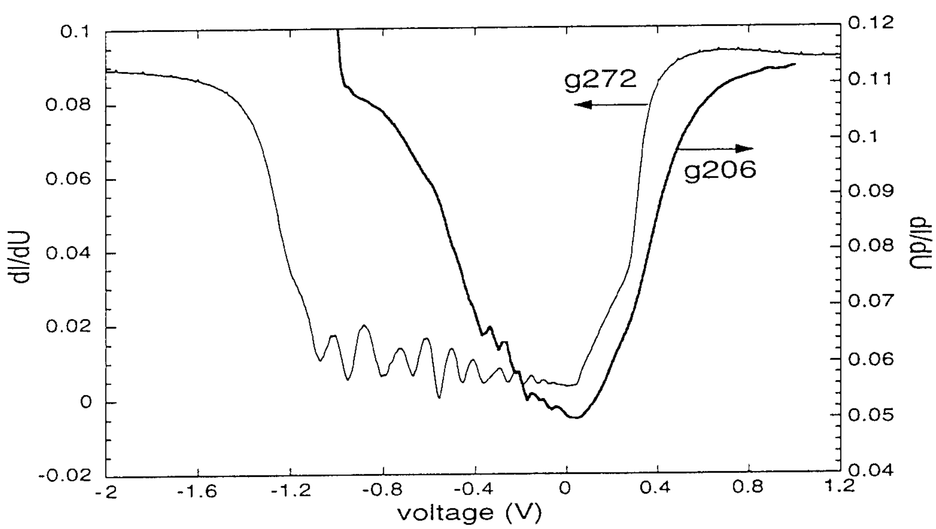


Figure 7: Conductivity vs applied voltage for two different samples. The resonances at negative voltages correspond to the calculated miniband arrangement.

maximise the surface of the active region, a grid mask is designed. This mask is designed in a way that the grating couples to the THz radiation. On the other hand, the very thin mesas ensures current uniformity through the structure. Different periods are available, optimised for different wavelengths.

We have observed a signal in the 1 to 3 THz spectral range from these samples. However due to the very low intensity a spectral analysis was not possible with the structures used. We are presently decining smal mesas to increase the emission intensity.